HEAD LOSS CHARACTERISTICS OF FLAP GATES AT THE ENDS OF DRAIN PIPES

J. A. Replogle, B. T. Wahlin

ABSTRACT. *Flap gates are commonly used at the end of pipe drains and pump outlets to prevent backflows of water and entry of small animals. Flap gates are relatively inexpensive, with low maintenance costs, but can trap debris in their hinge systems. Many texts refer to studies performed on flap gates at the University of Iowa in 1936, which may be limited in value because they are for specific "lightweight" gates. More recent studies in England have attempted to generalize the characteristics for pin–hinged flap gates and place the Iowa studies into a broader perspective. The flap–gate backpressure effect on a gate with free outfall appears to be small. However, under certain submerged conditions, a flap gate will increase the upstream backwater levels. This may be critical in sewerage situations and some surface land drainage cases. Recently, at least one manufacturer sells a rubber–coated steel gate cover with a flexure hinge made of the same rubber material. While it reduces the opportunity for trash to catch, such as may happen on a pinned–hinge type of pivot, this rubber hinge arrangement essentially becomes a spring–loaded gate with the force of closure due to both the weight of the gate and the elastic properties of the hinge. Users have questioned whether this arrangement introduces significant backpressure. We therefore tested a rubber–hinged flap gate to verify whether these gates fit into the general pattern of the limited previous studies on pin–hinged gates, which is to exhibit a continuous decrease in backpressure with increasing flow rate, and hence gate opening. The design information for pin–hinged flap gates is also updated to make it more readily available for design uses. The rubber hinge resulted in a slight deviation towards more head loss, approximately 3 mm (0.1 in.) at larger gate openings compared to about 1 mm (0.025 in.) for pin–hinged gates, which is attributed to the flexure strength of the rubber hinge. Thus, for free–flow outlet applications, flap gates of either the pinned–hinge or the flexure style add small head losses that amount to about 1% to 2% of the pipe diameter. These studies and the review of previous work allow users to evaluate whether flap gates of either the pinned hinge design or the rubberized flexure design can cause detrimental backpressure on a drainage system under free outfall situations.*

Keywords. *Drain outlets, Drainage, Drainage design, Flap gates.*

Flap gates are commonly used at the ends of pipe drains and pump outlets to prevent backflows of water and entry of small animals. Large sizes are frequently found in tidal areas to reduce inflows during high tides and permit outflows during low tides. Other uses are to prevent flood flows from an upstream storm from backing into lowlands during the passing of the flood flow. Under these conditions, the gate closes under the influence of its own weight and the hydrostatic pressure from the downstream side. When the water levels on the downstream side recede, the gate reopens and flow can again drain to the lowered receiving waters. These installations are relatively inexpensive, and maintenance costs are low. Malfunctions can occur when debris lodges in the gate opening or in the pinned hinges that are common to many types of flap gates, requiring regular inspections.

When properly maintained, flap gates can minimize backflow into drainage systems for most combinations of drainage flows and receiving stream water levels, even though the gate is expected to introduce some constriction on the flow that translates into an increase in upstream head. The effect on free outfall situations should be small (SCS, 1973). However, under certain conditions, when the receiving water level has receded to the point of being slightly lower than the previously protected lowland, a flap gate in the system will maintain a slightly increased upstream backwater level. This may be critical in sewerage situations and some surface land drainage cases. Just how much this increase will be at various levels of submergence, and at levels including free outfall, has been studied in only a few instances, and guidance is not well disseminated.

At least one manufacturer (Plasti–Fab) offers a rubber–coated steel gate cover with the hinge made of the same rubber material, making a total gate thickness ranging from 1.5 to 3 cm (0.75 to 1.2 in.) depending on the basic pipe diameter. Besides reducing the opportunity of trash to catch on a pinned hinge type of pivot, this rubber hinge arrangement acts as a spring–loaded gate, with the force of closure due to both the weight of the gate and the elastic properties of the hinge. While the existing information appears to support the idea that only small backpressure effects are generated from any flap gate (SCS, 1973; Burrows and Emmonds, 1988), users continued to question whether this

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was still true with the elastic–loaded closure. We therefore tested a flap gate on a pipe that was 20.3 cm (8 in.) in diameter to verify whether these gates fit into the general pattern of the limited previous studies.

BACKGROUND

Information on flap–gate characteristics is not abundant. Many texts refer to flap gates or tide flaps, including the classic book on sanitary engineering by Babbitt (1922 and subsequent revisions, including Babbitt and Baumann, 1958) and a more recent book by Linsley and Franzini (1979). Pethick and Harrison (1981) presented a theoretical treatment of rectangular flap gates. In 1936, the Hydraulic Laboratory of the (then) State University of Iowa conducted a series of tests to determine the head lost by water discharging through Armco–Calco flap gates (currently offered by Hydro Gate as model 10C flap gates). The gates, which were 46, 61, and 76 cm (18, 24, and 30 in.) in diameter, were supplied from commercial stock (Armco, 1978).

Burrows and Emmonds (1988) pointed out that the Iowa tests may be limited in value because they were for specific "lightweight" gates, and that Armco suggested that "heavy" gates may cause more head loss than their reported values of 15 mm (0.6 in.) for a 0.305 m (12 in.) flap gate and 110 mm (4.3 in.) for a 2.134 m (84 in.) flap gate. The terms "light" and "heavy" were not well defined. These values were extrapolated and interpolated by the Soil Conservation Service (SCS) (now the Natural Resources Conservation Service) in their internal Engineering Handbook Series as design guidance. Portions of that handbook, which include this guidance, are reproduced and quoted in SCS (1973, Section 16, Chapter 7, pp. 7–26). Burrows and Emmonds (1988) cautioned that the Iowa tests applied only to the gates tested and may not be relevant for general application.

Armco (1978) presented some quantitative head–loss information on gates that it manufactured, again based primarily on the Iowa studies. More recently, Burrows et al. (1997) reported on a British study with the objective to estimate flow rates based on flap gate opening. The analysis presented fit the data in a general sense, but values differed on the order of 20% to 30%. The most consistent data were for free discharge and no downstream submergence. The study also did not report the backpressure effects directly or the head losses that were experienced. Head losses for submerged gates were reported for two model gates by Burrows and Emmonds (1988).

Most or all of these flap gates have been the simple hinge–pin type with the hinge pin in the plane of the pipe end and gate–face contact plane. Burrows et al. (1997) consider the effects of the hinge being offset slightly upstream from this contact plane in their study of discharge ratings. Such an offset hinge mechanism is used in a weighted–gate system to control water levels in upstream irrigation canals (Raemy and Hager, 1998; Burt et al., 2001).

THEORETICAL CONSIDERATIONS

The flow situation from a flap gate is complicated, so a detailed theoretical approach is difficult. A dimensional–analysis approach was presented by Burrows and Emmonds (1988), but it introduces more variables than equations and cannot be directly applied. Burrows and Emmonds also conducted laboratory tests on two models with 80 mm (3.15 in.) and 135 mm (5.32 in.) gates of the configuration shown in figure 1, where most of the variables used herein are defined.

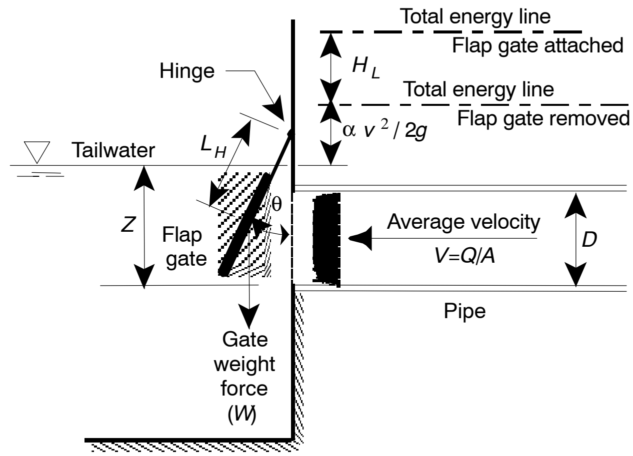

Figure 1. Definition sketch (modified from Burrows and Emmonds, 1988).

Burrows and Emmonds (1988) collected their data under slightly submerged conditions, and the data showed an increase in head loss due to the flap gates. Interestingly, the smaller flap gate exhibited about 30% more head loss than the larger gate. They attribute this increase to the relative length of the gate pivot arms (L_H/D), which is the distance from the gate center to the hinge–pin center (L_H) divided by the gate diameter (D) (fig. 1). Because the hinge arm is nearly the same length for both gate sizes, the relative length (L_H/D) varies from 0.71 for the larger gate to 0.85 for the smaller gate, or about 14% increase in L_H/D from the large to the small gate. Thus, the change in head loss (30%) seems to be about twice the change in L_H/D.

QUALITATIVE CONSIDERATIONS OF THE PROBLEM

For a flap gate, the backpressure effect at low heads in the pipe should be noticeable because the pressure component is used to force open the gate. Even relatively heavy gates will swing under relatively small pressures. For example, an iron gate about 1.25 cm (0.5 in.) thick with a mass of 15 kg (33 lb.) covering the end of a 38 cm (15 in.) pipe at an end angle of 1 horizontal to 10 vertical causes only a 15 N (3.3 lbf) component force as a capping pressure. The flap gate would start to open at an average over–pressure of 0.390 kPa (0.0566 psi), or 39 mm (1.6 in.) of water head, which is readily supplied by a partly filled horizontal pipe. If, however, a large flow exists and the pipe velocities become large, then the jet forces support the gate by the deflection of the jet, and the backpressure from the gate becomes even less noticeable. Thus, for a free–outfall flap gate at its higher range of flow rates, the energy to open the gate is "borrowed" from the downstream deflected jet, and little or no upstream backpressure is detectable. This qualitatively explains the behavior shown in figure 2, which was reconstructed for SI units from SCS (1973) for "light" flap gates with free outfall. As mentioned, the term "light" flap gate is not well defined but was used to refer to the Iowa selection of a commercial

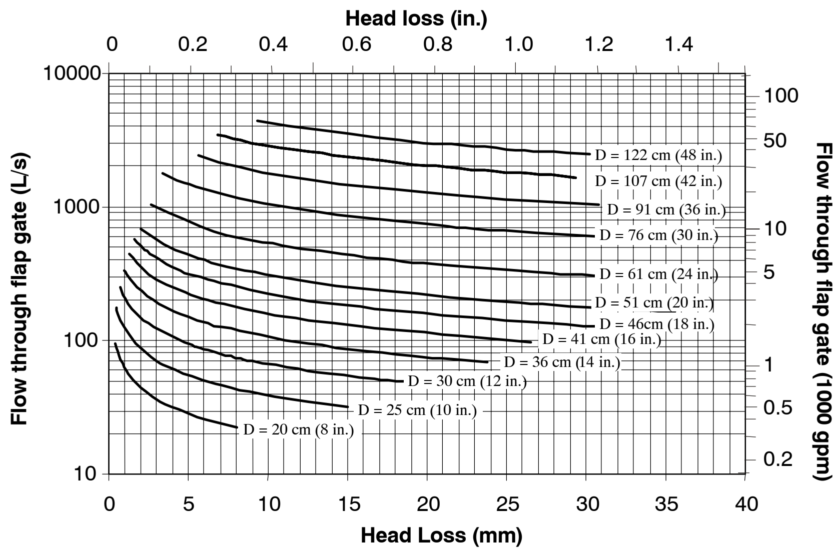

Figure 2. Head loss for "light" flap gates with free outfall (after SCS, 1973).

flap gate designed to withstand a backpressure head of 3 m (10 ft) of water. Note in figure 2 that as the flow rate for a given pipe size increases, the head loss decreases.

An equation that approximates figure 2 is:

$$\frac{H_L}{D}=\frac{1}{176}\frac{gD^5}{Q^2} \qquad (1)$$

where

g = acceleration due to gravity (9.81 m/s^2, or 32.16 ft/s^2)
H_L = head loss (m, or ft)
D = pipe diameter (m, or ft)
Q = discharge rate (m^3/s, or cfs).

Equation 1 was not derived directly from theory but rather from curves fit to the diagrams presented in the SCS reference. This equation does not account for changes in gate weight. However, it does illustrate the small backpressure that can be expected from the addition of a flap gate to the end of a drainage pipe with a free outfall.

Burrows and Emmonds (1988) indicated that the added head loss from a flap gate was reflected in the angle of the gate opening regardless of how it is achieved, by gate weight, spring, or manually applied force. This result was for submerged gates, where the submergence was to the elevation of the pipe top, Z/D = 1 (fig. 1).

Laboratory Verification

Laboratory studies were conducted to verify the above qualitative inferences. The flap gate shown in figure 3 was attached to the outlet end of a 20 cm (8 in.), Schedule 40 plastic pipe. The flap angle was about 15° from vertical. The flap gate opening was slightly larger and elliptical, 23 cm (9 in.) wide by 24 cm (9.5 in.) high. The pipe had piezometer taps at 30.5 cm (1 ft) intervals, with extra taps at 15.25 cm (6 in.) and 45.7 cm (18 in.) from the flap gate. The flow rate varied from about 35 to 85 L/s (1.25 to 3 cfs), and flow velocities ranged from 0.9 m/s (3 ft/s) to about 2 m/s (7 ft/s) in the flap gate outlet section.

Because the previous tests were for "light" flap gates mounted vertically with pin–type hinges, we attempted to verify whether the elastic hinge and the mounting at about 15° from vertical for the test gate behaved similarly. Expectations were that the sloping face would affect the initial low flow values because the weight component of the gate would inhibit opening. As noted, the gate would need to be very heavy to overcome the full pipe static head before flow begins.

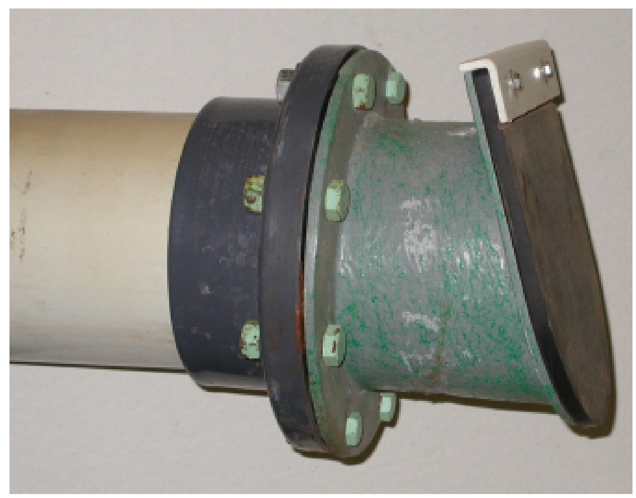

Figure 3. Flap gate with rubber flexure hinge.

The changes in backpressure readings were small, typically only 1 to 3 mm (0.025 to 0.1 in.), and challenged the limits of the standard vertical manometer system that was readily available. However, a large number of readings tend to reduce random error, so simple averages of readings from the 20 manometers were used. Slope–intercept comparisons did not fare better than the simple averages. Both methods produced similar data variation.

The pressure increase as read from the piezometers was noted for the flap gate in action and for the flap gate lifted out of the flow. This difference was interpreted as the increase in backpressure head due to the gate system being in place, and hence the additional head loss. Extra weights, either one or two, were fastened to the gate in the form of circular plates of steel 23 cm (9 in.) in diameter, each weighing 2 kg

(4.46 lb). The rubberized gate weighed about 2.8 kg (6.2 lb), including some small brackets used to hold the extra weights. These plates and the gate produced an 18 N (4 lbf) horizontal force on the end of the pipe, which was sloped back toward the flow at about 15° from vertical (fig. 3). As the gate swings upward, increasing horizontal force is needed, but eventually the dynamics of the flow, namely the impact of the flowing water and not the hydrostatic forces alone, sustains the gate. This combination of forces varies with the angle of the gate opening. The flexure of the rubber hinge causes an added force, again varying with the opening, of about 5.5 to 10 N (1.25 to 2.25 lbf), which further complicates the system.

Discussion of Results

The starting horizontal force needed to open the gate was about 18 N (4 lbf), plus that needed to overcome the flexure force, which was near zero in the closed position. This opening force at zero flow must come from the static pressure distributed over a flap gate area of 387 cm^2 (60 $in.^2$). This force is readily provided by the static head of the horizontal pipe, when filled, because the gate then has 20 cm (8 in.) of head against it with hydrostatic distribution, offering a potential static force of about 45 N (10 lbf).

In figure 4, the angle of the opening produced similarly small head losses, for the gate alone and with the addition of one added weight, shown in the figure as a dimensionless ratio to the velocity head, $h_v = V^2/2g$. Adding the second weight produced a significant increase in additional head loss (fig. 4). The date groups in figure 4 are fitted with power curves to compare with the Burrows and Emmonds (1988) curve. The free–outfall flap gate appears to have a threshold weight below which the backpressure changes slowly or not at all.

This increase in head loss is interpreted as exceeding the threshold weight for the behavior of a so–called "light" flap gate for this pipe diameter, and it indicates that the gate weight when two weights were added exceeded the ability of the hydrostatic pressure in a nearly non–flowing pipe to open the gate. However, we noted above that 45 N (10 lbf) are available and that only 18 N (4 lbf) are required to initially move the gate.

With the gate weight alone and with a high flow velocity, making the ratio of H_L/h_v low, the head loss approaches zero. Conversely, when the gate weight is large and the velocity head is low, backpressures increased significantly.

An explanation offered for why the head loss is greatest for low flow rates is that the hydrostatic pressure is used to hold the gate open until the velocity head can accomplish the task in free–outfall gates. The velocity head in these tests varied from 5 to 24 cm (0.2 to 0.8 ft). Thus, the velocity head value approaches that of the flap gate diameter. It appears that when the velocity head is of a magnitude that approaches or exceeds the pipe (gate) diameter, the additional head loss transmitted upstream approaches zero.

Also shown in figure 4 is an approximated average of Burrows and Emmonds (1988) results for submerged gates. Here, the gap angle is wider, probably due to the buoyancy forces on their light model gates, and the head loss values are greater, probably due to submerged conditions. There is no threshold static force due to the pipe being full and at rest, as with the free–outfall situations tested, because the tail water equalizes the pressure on both sides of the flap gate. The static head forces that are needed to open the gate, even with reduced force due to gate buoyancy, do not develop until there is a head increase between the upstream waters and the receiving waters. Being submerged, the velocity head energy cannot be "borrowed" from the downstream trajectory, and the turbulent flow losses around the gate flap are manifested as detectable backpressure in the upstream pipe system. The tradeoff between static pressure and velocity head, while it should still occur, affects the upstream backwater, hence the submerged flow curve does not approach zero (fig. 4). Rather, the indication is that the head loss (h_L) can vary from about one velocity–head ($H_L = V^2/2g$) in the pipe at low flows to less than one–tenth velocity–head at high flows. No head loss comparisons with gate angle or submerged flow were available for the SCS curves.

Burrows and Emmonds (1988) presented dimensionless plots of their results in terms of the dimensionless grouping $WD^2/\rho Q^2$ vs. angle of gate (fig. 5), where W is the gate weight, D is the pipe diameter, ϱ is the fluid density, and Q is the discharge rate. All of the data, regardless of gate weight, fell approximately on the same curve for the flap gate we studied, which had an L_H/D ratio of 0.5. The Burrows and Emmonds (1988) curves are for flap gates with extended hinge arms of L_H/D = 0.71 and 0.85 (see fig. 1). The progression is not continuous among the three curves. One

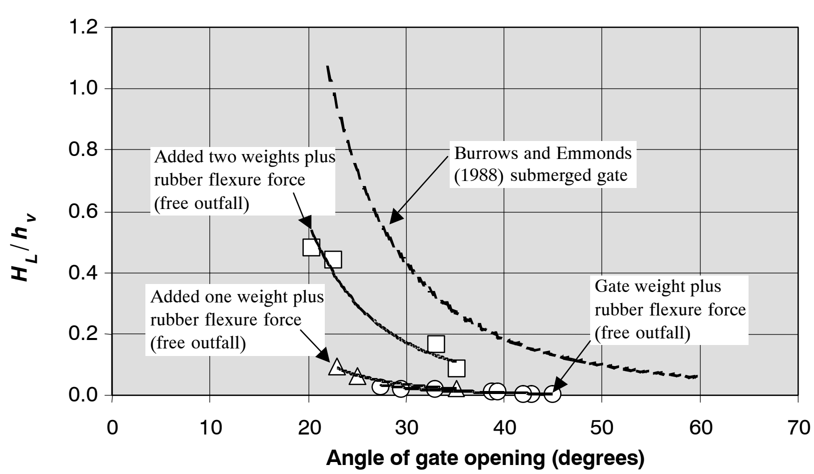

Figure 4. Head loss (H_L) relative to velocity head (h_v) as a function of flap gate opening and gate weight.

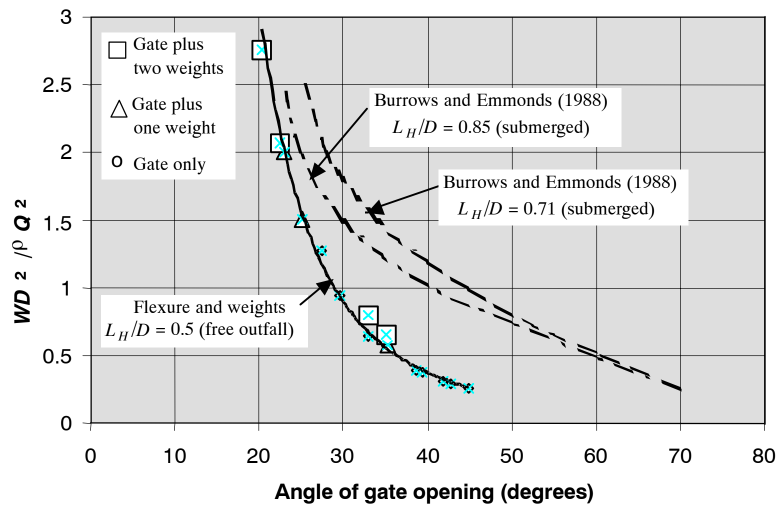

Figure 5. Gate weight (*W*), diameter (*D*), and discharge rate (*Q*) related to gate angle.

would expect that for a given flow rate, the longer arm would produce a smaller gate angle to achieve a required orifice opening. This indeed is indicated in figure 5 for the submerged flap gates of Burrows and Emmonds (1988), but the shorter arm of our test gate does not follow this pattern. Discharging around the gate into free air instead of under water is one possible explanation. Adding to that is the expectation that buoyancy forces of the submerged gates would increase the angle over that of unsubmerged conditions.

The angle of the gate opening as a function of the dimensionless grouping of figure 5 might be expected because the angle defines a quasi–orifice opening, and for orifice flow, the discharge rate is directly proportional to the area of the orifice opening but only to the square root of differential head.

In mathematical form, if a flap gate follows the behavior of an orifice, then the discharge (Q) is a function of the orifice area (A) and the differential head (h), or:

$$Q = CA\sqrt{2gh} \tag{2}$$

where C is a constant. If we take the log of both sides of the equation and the derivative of the equation, we obtain:

$$\frac{dQ}{Q} = \frac{dA}{A} + \frac{1}{2}\frac{dh}{h} \tag{3}$$

Thus, increases in Q can be accommodated by combined increases in A and h. The value of A is variable because the gate opens in response to increases in h, but changes in h are half as effective as changes in A. Moreover, A increases further from the impact of the velocity head ($h_v = V^2/2g$) caused by the increasing flow (Q). This means that the area (A) contributes more toward accommodating increases in Q than does h. In addition, h is gradually replaced by the velocity head (h_v) as the primary driver in opening the gate, which reduces the value of h. Making the gate heavier can be tolerated up to a threshold value, and then the flap gate angle for that particular flow rate changes when the impact force from h_v requires additional help from h (figs. 4 and 5).

Figure 6, in dimensionless format, hopefully would have unified flap gates in terms of gate weight force, diameter, flow rate, and head loss. It obviously does not. The gate weight (W) is the vertical force with no component forces calculated directly. The pivot arm length does not change for our gates when extra weights are added. Again, the smaller–weight condition and no–added–weight condition behave similarly. The second extra weight appears to indicate that backpressure can be transmitted upstream from free–outfall flap gates.

Figure 7, with discharge (Q) plotted against additional head loss (H_L), indicates that the additional head loss is about the same regardless of the flow rate, despite data variation for the weighted gate runs. This differs from the results for pin–hinged gates shown in figure 2 (re–plotted here as "pin–hinged gate"), which show decreased head loss with increasing discharge. The tested rubberized gate is assumed to be of lighter weight than the pin–hinged gates of figure 2. The test gate points would be expected to be to the left of and parallel to the pin–hinged gate curve, had the gate been pin–hinged itself. That most of the points appear to the right of, and do not parallel, the pin–hinged gate curve is attributed to the changing flexure force of the rubber hinge. The wider the angle of opening caused by the discharge rate, the more back force is generated by the flexure. This tends to maintain the additional loss to a more or less constant value throughout the discharge range, and it does not appear to parallel the pin–hinged gate curve until higher flow rates. Again, the idea of exceeding a threshold weight is supported by the wide spacing between the plotted points for one weight added and two weights added.

Figure 7 also shows that added weight increases backpressure, or additional head loss (H_L). The 18 N (4 lbf) force needed to initially unseat the heaviest test configuration requires a static head of about 5.6 cm (2.2 in.) of water depth on the gate face. However, recall that 45 N (10 lbf) are available as the pipe becomes full. Thus, the gate opens before the pipe is full, and velocity head conversion starts. Likewise, for the smaller weight, 12.7 N (2.86 lbf), or 4 cm (1.6 in.) of head are needed before the gate starts to open. Neither of these values is reflected in any direct way in figure 7, and no consistent pattern with gate weight is readily apparent. However, figure 7 supports the Armco (1978) suggestion that heavy gates may cause more head loss than their reported values. It also suggests that when the pipe must be nearly full to open the gate, then backpressure could

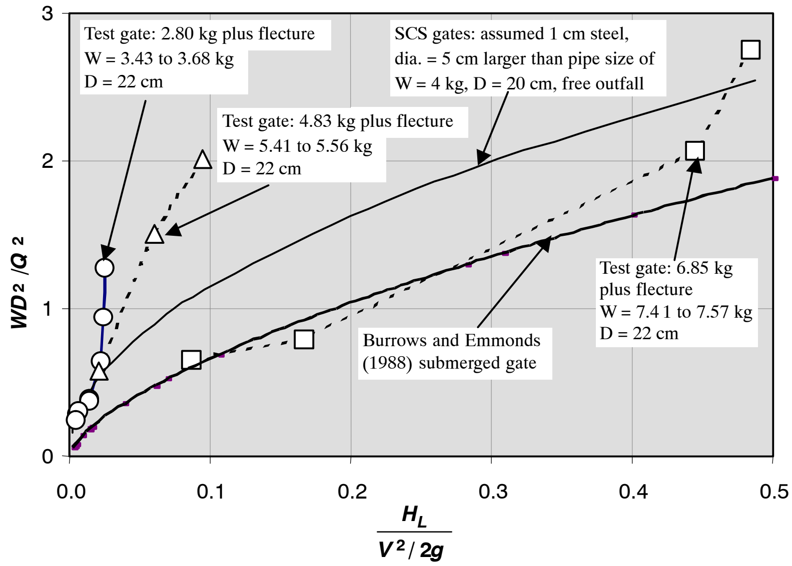

Figure 6. Dimensionless plots of flow parameters for several flap gates.

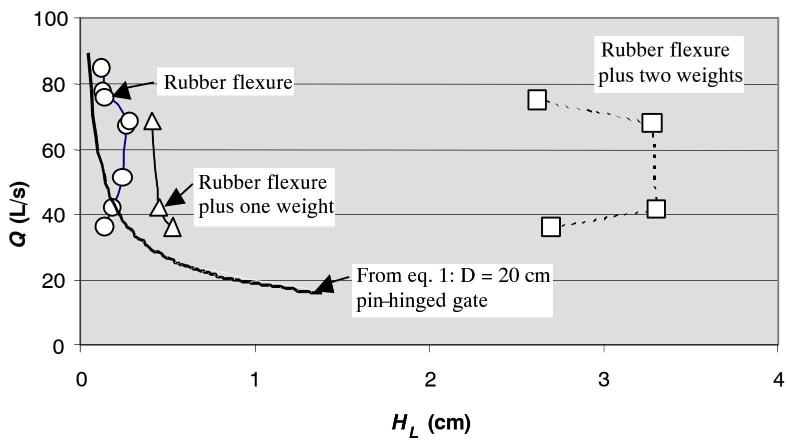

Figure 7. Comparison of pin–hinged gates to gate with flexure hinge and with added weight.

increase beyond the value for "light" flap gates. This idea of requiring a full pipe to start the opening of the gate could serve as the separation between "heavy" and "light" gates. However, the opening force is also a function of the slope angle of the flap gate mounting, which complicates the definition.

Other Considerations

In an agricultural drainage system in which the drain pipes usually flow partly full, the effects of adding a "light" flap gate such as the one tested are nearly undetectable. In submerged situations, an increase in upstream backwater can be expected, but the effect should be small, reflected more as an increase in time to drain the final increment of water than on the final drainage level, because the gates seldom seat tightly without significant backpressure from downstream. Flap gates can be installed so that they remain underwater, as recommended by Armco (1978), to slow corrosion that repeated wetting and exposure to air can cause. In addition, floating debris is more of a problem for gates that alternate between free and submerged flow. Debris clogging is of less concern on freely discharging gates.

Another consideration is the extrapolation of these results to other pipe sizes. Standard hydraulic modeling laws indicate that the results will reliably scale to length ratios of at least 10, if the length dimensions of all parts are similar.

Example Application

Situation

A low–lying, level, 4 ha (10 acre) farm field is surface drained through a levy berm with a 20 m (65 ft) length of 20 cm (8 in.) smooth plastic pipe into a creek with a non–flooding water surface only 50 cm (20 in.) below the field surface (fig. 8). The pipe bottom outlet is only 0.25 m (10 in.)above the stream surface. The inlet is depressed at the field end with a flared–cone inlet structure that reduces inlet losses, so that the hydraulic grade line is affected primarily by the change in velocity head. The pipe is installed horizontally through the berm. Frequent flows from upstream can temporarily inundate the outlet to 1.5 m (5 ft) deep for up to 12 hours and cause flooding in the cropped field, even when there are no local rains. It is suggested that a flap gate be attached to the pipe outlet.

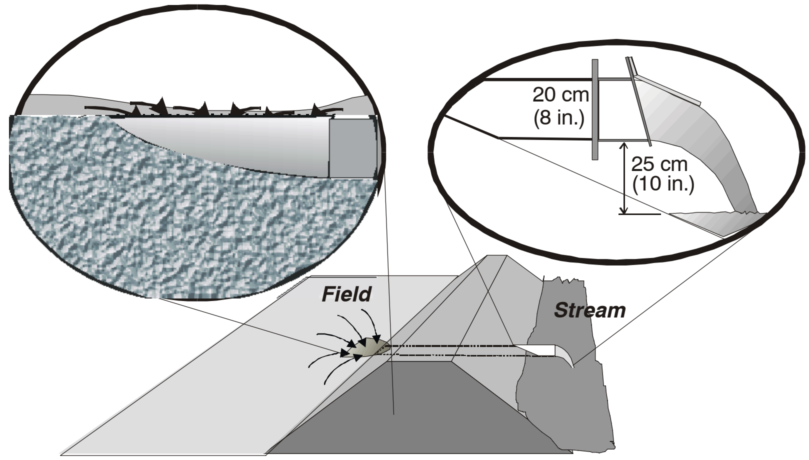

Figure 8. Example drainage situation.

Required

Design (select) a standard, “light,” hinged flap gate for this pipe outlet. Comment on the increase in backpressure that is calculated. How might this affect the field to be protected?

Discussion and Solution

Standard hydraulic calculations, using 1.5 m (5 ft) of head on smooth pipe, indicate that the pipe could carry approximately 113 L/s (4 cfs, or 4 acre–inches per hour) at the maximum stream depth over the pipe outlet of 1.5 m (5 ft). Under pre–flap–gate conditions, the field could receive about 36 acre–inches backwards through the pipe, or 9 cm (3.6 in.) on the field. This would later drain at a slower rate when the receiving stream lowered.

Using standard pipe flow calculations again, the drainage flow would only have about 30 cm (1 ft) of head instead of 1.5 m (5 ft) and would flow at only about 51 L/s (1.8 cfs). This would more than double the time that was needed to inundate the field. However, depending on the subsoil water table, much of this flooded water could be expected to infiltrate in less than a day. Thus, the drain–back time may approach, or be less than, the inundation time of 12 hours. Local rains would aggravate this on the field. A flap gate would limit the drainage and field inundation to local rainfall amounts minus infiltration.

Standard Flap Gate Design Selection

From figure 2 or equation 1, D = 0.2 m (0.66 ft or 8 in.), Q = 0.051 m^3/s (1.8 cfs, or 808 gpm), and g = 9.81 m/s^2 (32.2 ft/s^2) yields 0.0014 m = 1.4 mm (0.0047 ft = 0.056 in.) head loss. This is judged to be insignificant, and the gate can be added with negligible effect on the drainage time.

Because the gate is frequently submerged, the hinge could be subjected to trash entanglements. Thus, a rubberized flap gate might be indicated to avoid trash accumulation. Estimate the backpressure that can be expected in the pipe and the influence this rubberized flap gate might have on the draining times from the field.

From figure 7, the backpressure increase from a rubberized flexure hinge is about 3 mm (0.1 in.) of water head at about 50 L/s (800 gpm) flow rate. This is nearly double that for the pin–hinged gate but is still low enough not to materially affect drainage rates.

Thus, the rubberized flap gate can be used in this example with advantage. Protecting the area from back flooding leaves only local rainfall. Even a relatively heavy rain of 10 cm (4 in.) should be drained within a day after the stream flow recedes.

Submerged Flow

The drainage starts when the flap gate is slightly submerged and the field water level is still higher than the stream surface. In this case, the flow does not start until the gate buoyancy weight is balanced by the slight overpressure from the field–level water. The net force moment on the 2.8 kg (6.2 lb) rubberized gate (ignoring buoyancy) mounted at 15° must be 27.5 N (6.2 lbf) acting about the hinge at 2.73 cm (1.075 in.), or 75 N–cm (6.66 lbf–in.) must be countered by a uniform overpressure (P) in the pipe acting at the center distance of 10 cm (4 in.) from the hinge (the hydrostatic forces and hydrostatic distributions inside and outside the gate cancel), or a moment of $P \times$ 10 cm (4 in.), or P = 7.4 N (1.67 lbf) distributed over an area of 325 cm^2 (50.2 $in.^2$), or an overpressure of 2.3 cm (0.92 in.) head differential before the gate cracks open and a small flow begins.

The assumed heavier gate of figure 6, weighing 4 kg (8.8 lbs), would increase the backpressure to about 3 cm (1.2 in.) of water head. Thus, the increased backpressure at opening for either the “light” pin–hinged gate or the rubber–hinged gate would be on the order of 2.5 cm (1 in.) of water head and would decrease with gate opening for either gate.

CONCLUSIONS

Rubber–hinged flap gates added to the end of a drain pipe do not create significant flow restrictions in the usual operating ranges for horizontal pipes discharging freely. When discharging into air, the influence is about 3 mm (0.1 in.) of additional head loss for an operating range of discharges from 35 to 85 L/s (1.25 to 3.0 cfs) in a 20 cm (8 in.) pipe.

Head loss in pin–hinged gates is inversely proportional to discharge rate. Rubber–flexure hinges tend to cause a nearly constant head loss regardless of flow rate. However, the resulting backpressure is still small, on the order of 1% of the pipe diameter.

The additional head loss due to adding a flap gate to a freely discharging pipe is minimal because the energy to open the gate at higher flow rates is taken from the trajectory energy of flow, essentially after the flow has exited the pipe, and hence little or no backpressure is detected.

Previous studies by others indicate that submerged gates cause greater head loss than freely discharging gates, which may be a factor in lowland drainage situations. This loss is only roughly characterized, and may be on the order of 0.1 to 1 times the velocity head (h_v) for high to low flow rates, respectively.

The angle of the flap gate opening is a function of $WD^2/\rho Q^2$. The angle of opening for a given discharge and flap gate is expected to behave as an orifice, meaning that the change in the area of the opening is directly proportional to the discharge rate but only to the square root of head change. Because the static pressure is directly proportional to head, and the velocity forces are proportional to the square of the velocity, it appears that a change in area is more readily accomplished than a change in differential head, and thus the head becomes inversely proportional to discharge.

These studies and the review of previous work allow users to evaluate whether flap gates, of either the pin–hinged or rubber–hinged design, can cause detrimental backpressure on a drain outlet system under free outfall and submerged outlet situations.

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